AFRL-ML-WP-TR-2001-4031

METHOD TO TRACK CORROSION ENVIRONMENT IN AIRCRAFT

SUNIL MENON
STEVE LEWIS
RON JIRACEK

HONEYWELL LABORATORIES, INC.
3660 TECHNOLOGY DRIVE
MINNEAPOLIS, MN 55418

JANUARY 2001

FINAL REPORT FOR 01 SEPTEMBER 1999 – 31 DECEMBER 2000

MATERIALS AND MANUFACTURING DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7750

Form SF298 Citation Data

Report Date ("DD MON YYYY")	Report Type	Dates Covered (from... to) ("DD MON YYYY")
00012001	Final	01091999 31122000

Title and Subtitle Method to Track Corrosion Environment in Aircraft	**Contract or Grant Number**
	Program Element Number
Authors Sunil Menon, Sunil; Lewis, Steve; Jiracek, Ron	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Honeywell Laboratories, Inc. 3660 Technology Drive Minneapolis, MN 55418	**Performing Organization Number(s)**
Sponsoring/Monitoring Agency Name(s) and Address(es) MATERIALS AND MANUFACTURING DIRECTORATE AIR FORCE RESEARCH LABORATORY AIR FORCE MATERIEL COMMAND WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7750	**Monitoring Agency Acronym**
	Monitoring Agency Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes	
Abstract	
Subject Terms	
Document Classification unclassified	**Classification of SF298** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** unlimited
Number of Pages 41	

NOTICE

WHEN GOVERNMENT DRAWINGS, SPECIFICATIONS, OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY GOVERNMENT-RELATED PROCUREMENT, THE UNITED STATES GOVERNMENT INCURS NO RESPONSIBILITY OR ANY OBLIGATION WHATSOEVER. THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA, IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE IN ANY MANNER CONSTRUED, AS LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR AS CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE, OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

THIS REPORT IS RELEASABLE TO THE NATIONAL TECHNICAL INFORMATION SERVICE (NTIS). AT NTIS, IT WILL BE AVAILABLE TO THE GENERAL PUBLIC, INCLUDING FOREIGN NATIONS.

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

THOMAS J. MORAN, Project Engineer
Nondestructive Evaluations Branch
Metals, Ceramics & NDE Division

JAMES C. MALAS, Chief
Nondestructive Evaluations Branch
Metals, Ceramics & NDE Division

GERALD J. PETRAK, Assistant Chief
Metals, Ceramics & NDE Division
Materials & Manufacturing Directorate

COPIES OF THIS REPORT SHOULD NOT BE RETURNED UNLESS RETURN IS REQUIRED BY SECURITY CONSIDERATIONS, CONTRACTUAL OBLIGATIONS, OR NOTICE ON A SPECIFIC DOCUMENT.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 2001	Final Report, 09/01/1999 – 12/31/2000

4. TITLE AND SUBTITLE
Method to Track Corrosion Environment in Aircraft

5. FUNDING NUMBERS
C: F33615-97-D-5271
PE: 62102F
PR: 4349
TA: 40
WU: 01

6. AUTHOR(S)
Sunil Menon
Steve Lewis
Ron Jiracek

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Honeywell Laboratories, Inc.
3660 Technology Drive
Minneapolis, MN 55418

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

MATERIALS AND MANUFACTURING DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7750
POC: D. Thomas Moran, AFRL/MLLP, 937-255-9800

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
AFRL-ML-WP-TR-2001-4031

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 Words)*
A Corrosion Environment Monitoring (CEM) system was developed as a data acquisition device designed to collect and store environmental data for military and commercial aircraft. Accurate and robust commercial off-the-shelf (COTS) sensor systems are combined with state-of-the-art processing units to capture and store a wide range of physical data related to the corrosion phenomena. The collected sensor data include temperature, humidity, pH concentration, chloride ion concentration, and the free potential of aluminum. The collected data can then be used in predictive maintenance and other history-based prognostics. The data stored on a PC card is transferred to a host PC using the CEM Analysis software for postcollection display and analysis.

14. SUBJECT TERMS
Corrosion, Corrosion Environment Monitoring (CEM) software

15. NUMBER OF PAGES
44

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

Executive Summary

The Corrosion Tracker program to develop the Corrosion Environment Monitoring (CEM) system was performed by Honeywell Laboratories in Minneapolis, Minnesota, and funded by Wright-Patterson Laboratories. The CEM system is a data acquisition device designed to collect and store environmental data for military and commercial aircraft. Accurate and robust commercial off-the-shelf (COTS) sensor systems are combined with state-of-the-art processing units to capture and store a wide range of physical data related to the corrosion phenomena. The collected sensor data include temperature, humidity, pH concentration, chloride ion concentration, and the free potential of aluminum. The collected data can then be used in predictive maintenance and other history-based prognostics. The data stored on a PC card is transferred to a host PC using the CEM Analysis software for postcollection display and analysis.

The CEM is composed of two modules interconnected by a shielded cable containing eight twisted-wire pairs (16 single wires). One of the modules, the Sensor Module, contains four COTS sensors: a chloride-ion sensor, a pH sensor, a humidity sensor, and a temperature sensor. A fifth sensor, a free-potential electrode, is a specially built electrode constructed of the specific material being monitored for corrosive damage. The free-potential electrode can be easily interchanged to monitor the corrosion of another material.

The second module is the Electronics Support Module (ESM). The ESM controls the overall CEM system and includes: a PIC processor for I/O control and data analysis, a flash card memory for data storage, a low-power LCD display supported by a dedicated display processor with associated switches to control the display and CEM functions, and a power supply consisting of two AA batteries. The CEM also has a real-time clock that controls the data-sampling rate and timestamps the data. A photo of the CEM hardware units is shown in Figure 1.

This report contains a technical discussion of the CEM device and referenced documents, including a discussion of the mechanical, electronic, and software design.

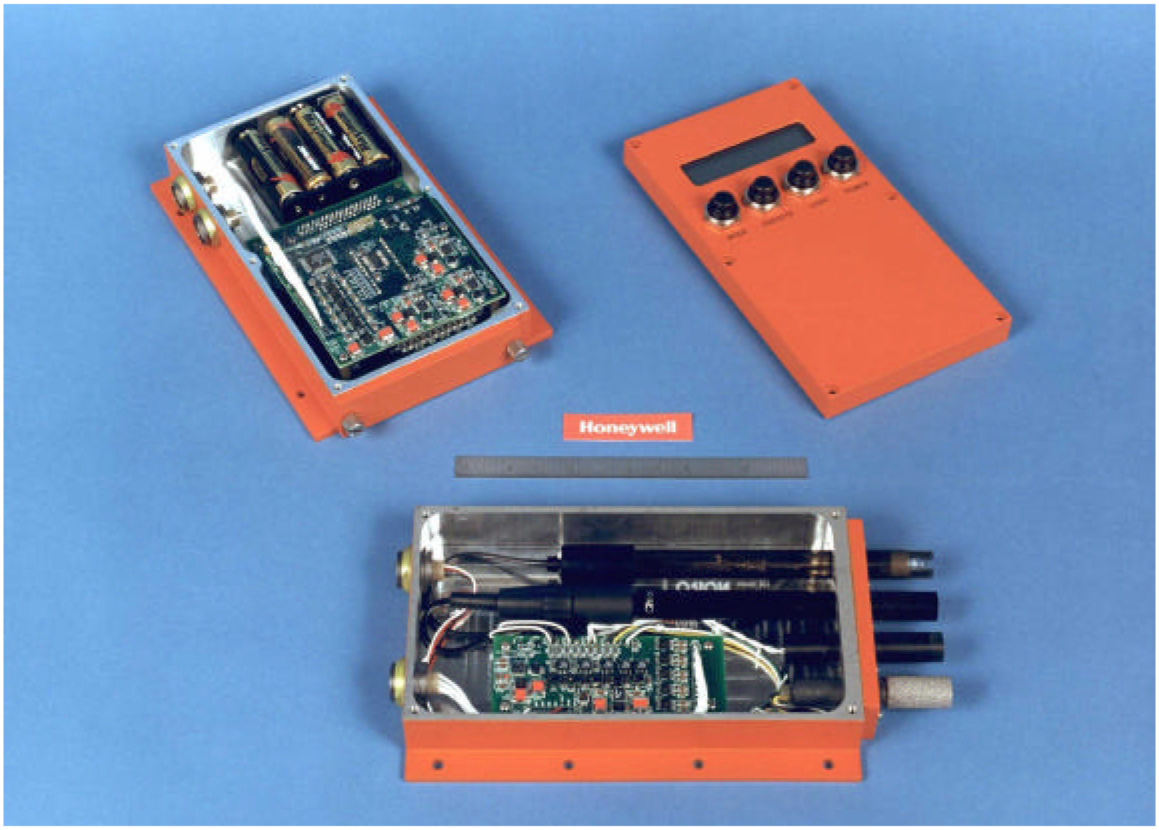


Figure 1. Photo of the CEM Unit—Sensor Unit and Electronic Support Module

Introduction

The Corrosion Environment Monitoring (CEM) system is a data acquisition device designed to collect and store environmental data for military and commercial aircraft. Accurate and robust commercial off-the-shelf (COTS) sensor systems are combined with state-of-the-art processing units to capture and store a wide range of physical data related to the corrosion phenomena. The collected sensor data include temperature, humidity, pH concentration, chloride ion concentration, and the free potential of aluminum. The collected data can then be used in predictive maintenance and other history-based prognostics. The data stored on a PC card is transferred to a host PC using the CEM Analysis software for postcollection display and analysis.

Background

The corrosive environment monitor grew out of prior work at the Honeywell Technology Center that yielded Patent No. 5,549,803, titled “Smart Fastener.” The Smart Aircraft Fastener Evaluation (SAFE) system, shown in Figure 2, was developed to detect the corrosion process occurring in the lap joints of aircraft skins or within aircraft structural members. Its unique features were its small sensor size and the concept of embedding this sensor within a standard aircraft fastener. The SAFE system was not designed to monitor a general environment. It relied on a special microsensor array (i.e., sensors on a chip) that was developed for Honeywell by the Lawrence Livermore National Laboratory. This microsensor array was not adequately tested to verify its functionality or reliability.

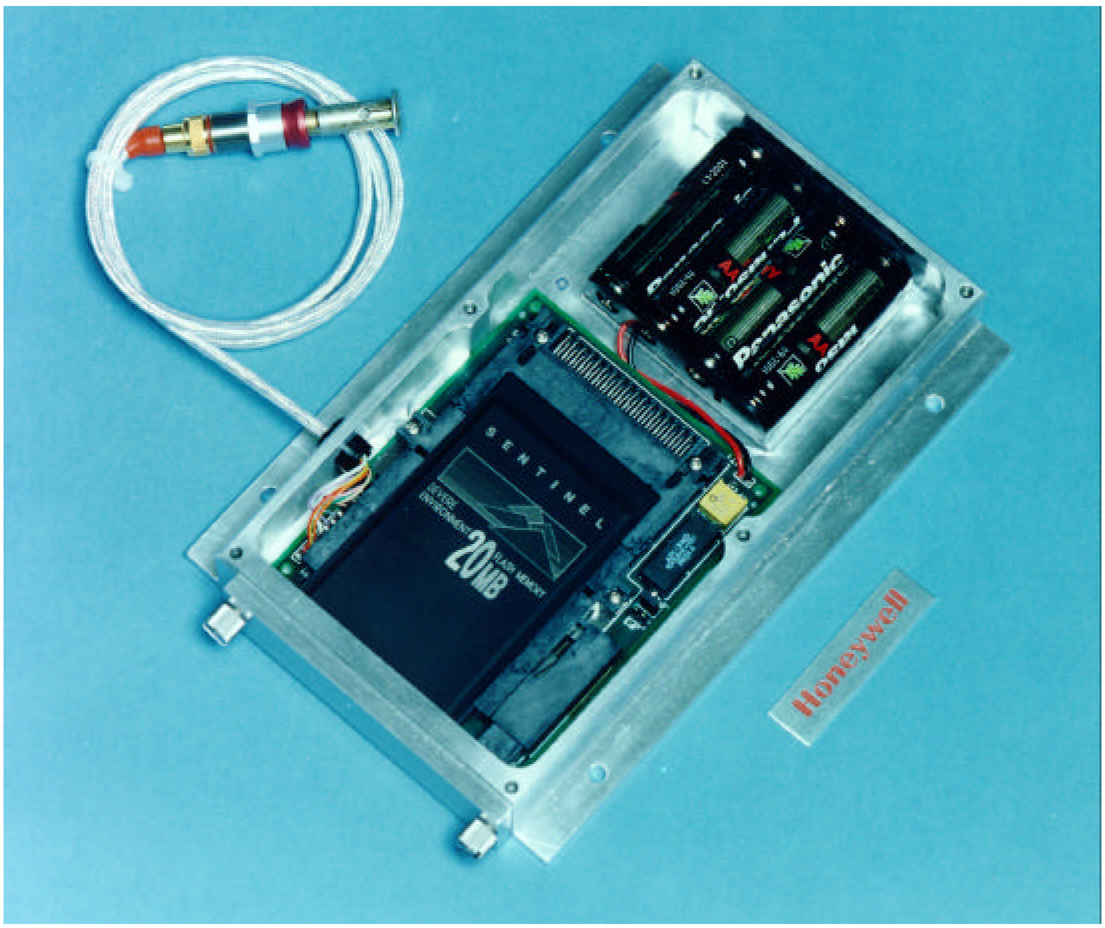


Figure 2. SAFE System Showing Sensor and Data Recorder with the Cover Removed

The current CEM system addresses and overcomes several problems with the SAFE system. In its general application, the CEM provides a basis for performing corrosion inspections on a “condition” or “exposure” basis rather than on a preestablished schedule basis, and it provides the necessary metric, an exposure index, on a real-time local display. The exposure measure monitors a larger area of exposure rather than a very small and localized area. The CEM also uses COTS sensors, thus eliminating the risks associated with special-purpose, custom microsensors. Finally, an interchangeable free-potential electrode allows the CEM to be easily modified for the specific material and area to be monitored rather than requiring the costly processing of a new integrated sensor circuit structure on an IC process line.

The Smart Fastener was designed to work with and be supported by an offline PC. Data collected by the SAFE system was transferred via a flash card memory to the support PC for analysis and readout. The onboard system had no display capability or even an “on/off” switch. The CEM includes a low-power LCD display and push buttons so the user can directly read out the system and can control the displayed outputs. The user can thus choose to display the current value of each sensor, the dose exposure index, or the result of a built-in-test check. The user can also activate the CEM from its powered-down mode.

In summary, the CEM has been implemented for broad applicability and convenient use. It can be used to monitor the potential corrosion activity in any area where moisture collects.

CEM Hardware

The CEM hardware evolved from the original SAFE program. The SAFE system consisted of a custom sensor unit, a PCMCIA card for data storage, a RAM chip, and a PIC microcontroller. The microcontroller would wake up at predefined time intervals and take sensor readings. After reading the sensors, the processor would set its internal wake up timer and then go to sleep. After enough sensor readings were taken to fill up the RAM, the data was written to the PCMCIA nonvolatile memory. The user could then debrief the unit by removing the PCMCIA card from the unit and inserting iut into a PC that is running a Visual Basic application which formats the data file. The sampling parameters can be set using the same Visual Basic program; the card is then reinserted into the SAFE unit and resumes taking data at the specified intervals. More information on the Visual Basic program can be found in the software section.

Two significant changes were made to the SAFE system to create the CEM unit. First, the custom sensor unit was replaced with off-the-shelf sensors that were moved into a separate module and connected to the recorder using two cables. This was done for two reasons: (1) the custom sensor unit was no longer available for a variety of reasons, and (2) the off-the-shelf sensors were much less expensive. The new sensors were put into a separate unit so that the recorder did not have to be collocated with the sensor unit that is installed in hard-to-reach areas such as under the floor of a helicopter. The second major change between the SAFE and CEM units was to add a time keeping RAM, along with an LCD display for obtaining status information. This change was accomplished by removing the RAM that was on the original SAFE board and adding a connector to a custom-developed daughterboard. The daughterboard includes an LCD display driver, interface electronics that talk to the sensor module, and a RAM that doubles as a real-time clock. The LCD displays the current status of the unit. The readings from the sensors go both to the main board to be recorded and to the microcontroller that drives the LCD so that the current sensor readings can be displayed.

Electronics Support Module (ESM)

The ESM unit consists of three printed circuit boards: the existing SAFE board as the motherboard, a daughterboard, and a third board that implements a battery shutoff circuit.

The motherboard includes a PCMCIA card, a PIC microcontroller, several analog-to-digital (A/D) converters, and a connector to the daughterboard. The PIC controls the data sampling, as well as the power management for both the recorder unit and the sensor module. When a PCMCIA card is inserted into the CEM unit, the PIC reads the configuration information that was previously stored on the card using a Visual Basic application (discussed in the software section) running on a separate computer. The configuration information tells the PIC which sensors to sample using the A/D converters and the sample rate for each sensor (which the user can vary from sensor to sensor). The PIC then reads the time from the time-keeping RAM and writes this timestamp on the PCMCIA card. The PIC then goes into a very low power sleep mode. The PIC wakes up briefly every minute to see if it is time to sample any of the sensors; if not, it goes back to sleep. If it is time to sample, the daughter board and the sensor unit are then powered up, and data is taken after a short delay to allow the sensors to settle. After sampling a sensor, the PIC stores the data temporarily in the time-keeping RAM, which is located on the daughterboard. When this RAM fills up (512 bytes), the PIC transfers the data from the RAM to the nonvolatile PCMCIA memory card and then starts filling the RAM again. This is repeated until the PCMCIA card is removed for debriefing.

The daughterboard includes a PIC microcontroller that acts as an LCD display driver, as well as decoding the four user input buttons, line driver receivers, a power supply, and signal conditioning circuits. The daughterboard can be powered up either by the motherboard when it is time to sample data or by the user pushing the power button. When the motherboard is sampling, the line driver receivers and the signal conditioning circuits are turned on and the output data is passed down to the A/D converters on the motherboard. The daughterboard will also respond to the button pushes made by the user. The LCD and the four buttons can be used to gather CEM status information. The user can interrogate each of sensors individually or run a built-in test that checks to see if the sensor readings are reasonable. The user can also check on the battery voltage. The user interface modes are explained in the software section.

The battery monitoring circuit is implement on the third printed circuit board. The purpose of this board is to monitor the battery voltage and cut off power to the recorder unit once the battery is drained. This prevents the user from overdraining the battery, which causes it to corrode and creates a mess. The battery cutoff is set for approximately 3.6 V, which corresponds to when each of the four AA cells is down to 0.9 V.

Sensor Module

The sensor module consists of five sensors, one sensor printed circuit board, and two pre-amplifier boards. The sensors are a combined humidity and temperature probe, a free-potential electrode, a chloride ion detector, and a pH sensor. The printed circuit board consists of some signal conditioning circuits, power supplies, and some line drivers so that the analog signals can be driven over the 15-foot cables. The sensing end of each of the sensors protrudes through the housing to the environment being sensed. A rubber gasket around each of the sensors ensures that the sensor module is watertight. The free potential, chloride ion, and pH sensors are fed into a preamplifier board that isolates these sensors from each other. All the sensors are then sent into a second preamplifier board that provides a high-impedance buffer stage. Finally, the outputs are sent down to the signal conditioning circuitry and then into the line drivers to send the signals through the cables back to the recorder unit. The recorder unit provides the power management along with the power itself. The battery voltage provided is converted to both +5 V and –5 V, which the line drivers require.

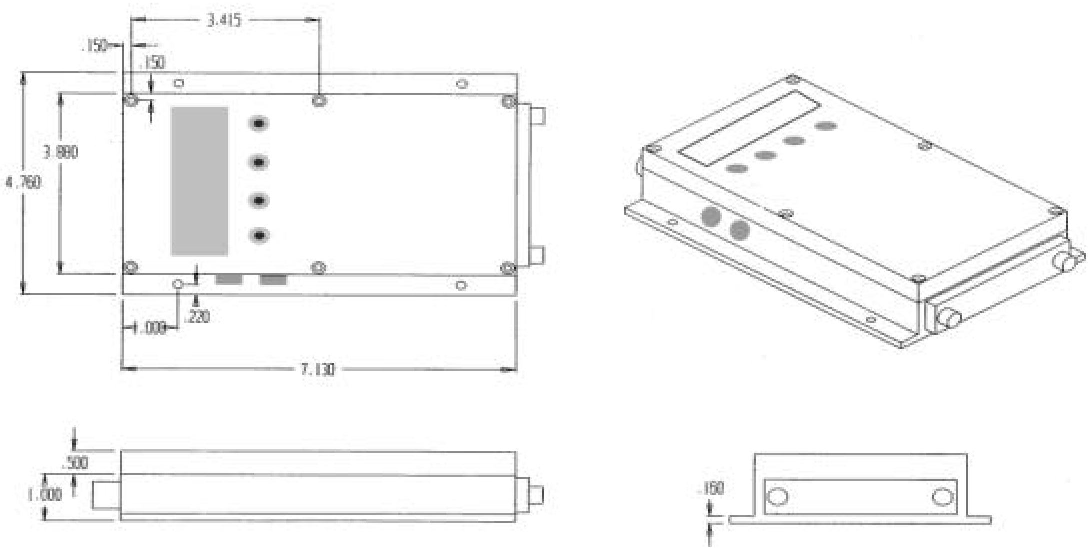


Figure 3. Electronics Support Module

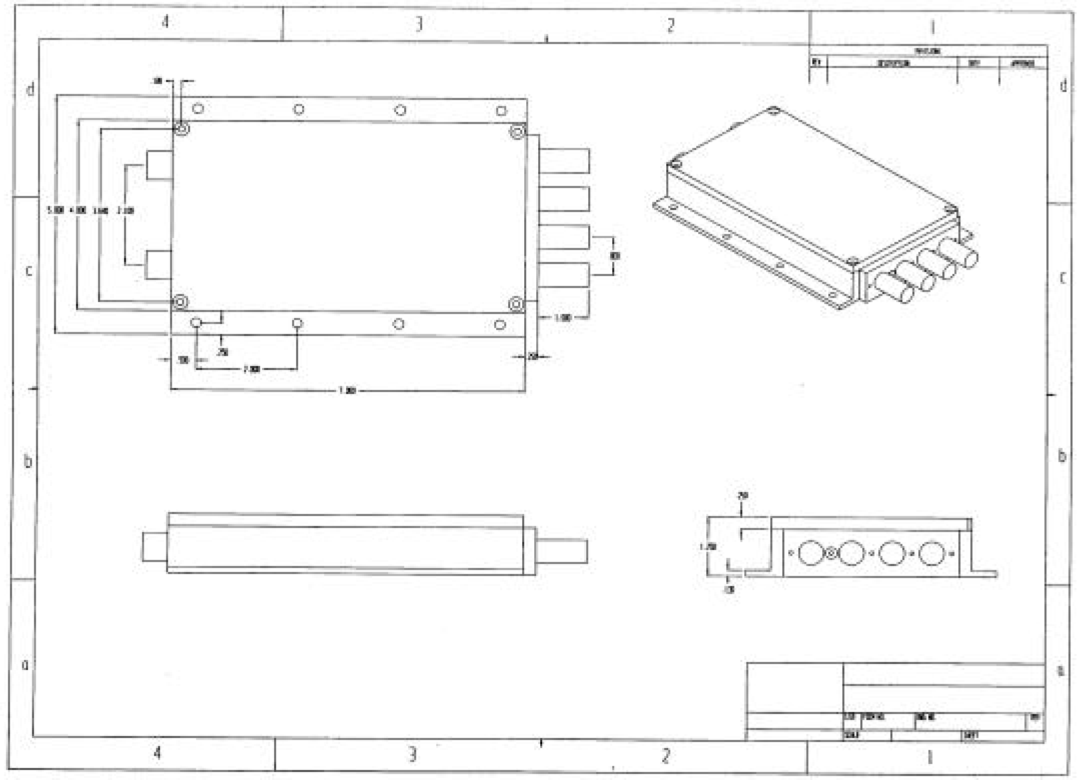


Figure 4. Sensor Module

Appendix

Corrosion Environment Monitor (CEM) Software Users Manual

CEM Host Software Users Manual

CEM Evaluation System
Version 1.0
August 12, 2000

Honeywell Laboratories
3660 Technology Drive
Minneapolis, Minnesota 55418

Table of Contents

Section 1
System Overview

The Honeywell Corrosive Environment Monitor (CEM) system consists of multiple environmental sensors coupled to a long-term battery-operated data recorder and a host computer system equipped with a PC Card (formerly PCMCIA) socket. The sensor electrodes are mounted inside the sensor module, which samples environmental and chemical conditions as they exist in the aircraft.

Section 2
Installation

Several components make up the CEM host system. These include the

- CEM Host Interface Program and
- PC Card (formerly PCMCIA) solid-state hard disk.

Installation instructions for each of these components are presented in the following sections. Read through each section before beginning installation, and pay careful attention to any special notes or warnings.

2.1 Host Interface Software Installation

The host control and communications program (CEM Host Interface Program) is a 32-bit Windows application developed with Microsoft Visual Basic version 6.0. Installation is accomplished by running the *setup.exe* program found on the media distribution CD-ROM. In Windows95, this can be done by selecting the RUN command from the START menu and browsing to the CD-ROM (see Figure 2.1).

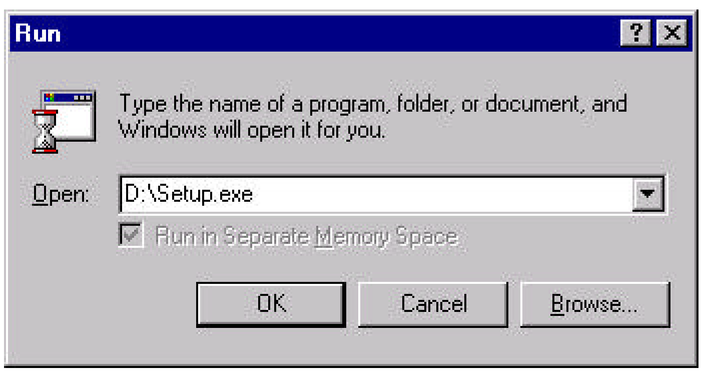


Figure 2.1: Running the host setup program from the CD ROM on a Windows95 PC.

The setup program for the CEM Host Interface Program is menu driven and has several installation options. Most decisions are automatic and follow common protocols.

The user must choose a target directory into which the CEM host program files will be loaded. The default is C:\Program Files\CEM\. Any valid path may be entered. After selecting the target directory, press the large button with the picture of a PC to continue.

A progress indicator provides information on the installation process. Follow the directions carefully. At the end of the procedure, the setup program will create an execution icon in the Windows95 expanding START menu. Selecting this icon will run the CEM Host Interface Program. The executable installed into the target directory is named *CEM.exe.* Section 3 details CEM Host Interface Program operation.

2.2 PC Card Flash Disk Installation

A PC Card (formerly PCMCIA) flash disk is used to store and transfer data collected by the CEM recorder to the host system. This solid-state card is recognized and configured by the Windows95 operating system as a standard hard disk and appears under file selection menus as a lettered drive. The solid-state disks have been formatted and given the volume labels “CEM Disk”; they will be referred to in this document as CEM Disk.

The *plug’n’play* drivers of Windows95 automate card installation. In typical systems equipped with a PC Card socket(s), the user need only insert the card into an empty socket after the PC has been booted and the operating system has finished loading. Commonly, a tone sequence confirms recognition of the card.

NOTE: The data file “CEM.txt” on the CEM Disk is not to be modified directly by the user through the Windows95 operating system. The file is editable directly from the window manager, and there are no safeguards to prevent user corruption of the data file. The CEM Disk should be removed from the host computer when not in use to prevent unauthorized file manipulations.

Section 3
Host Software Operation

After Installation, run the CEM Host Interface Program by selecting the *CEM.exe* executable in the START menu. It is best to have the CEM flash disk inserted and functioning prior to executing the Host Interface Program, and that the disk is not removed until after the program has been exited. After running the program, the main control panel shown in Figure 3.1 is loaded.

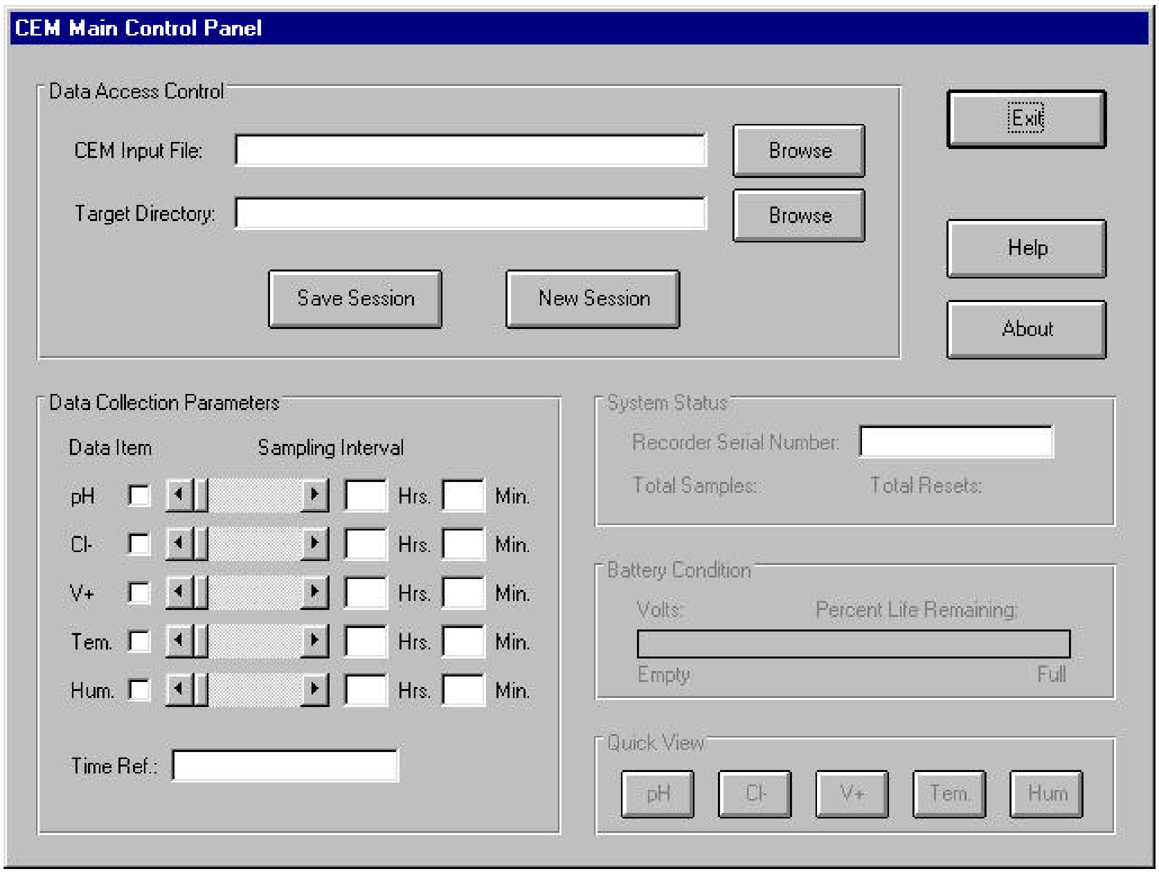


Figure 3.1: CEM Host Interface Program main control panel.

This form is divided into three major sections: Data Access Control, where file locations and save commands are executed; Data Collection Parameters, where the sampling rates and channel selections are made; and the System Status, Battery Condition, and Quick View sections, which provide debrief information. At startup, status information is not displayed because the recorded data file has not been processed.

The sampling rates, time reference, and data associated with a SESSION are stored in a single file on the CEM Disk called “CEM.txt”. This fixed-size session file is the only file on the CEM Disk. It has been created by the manufacturer and resides at fixed address blocks in the logical disk space. The file contains 14,002 blocks of 512 bytes for a total size of 7,169,024 bytes. The first two blocks contain sampling rate information and the time reference, and the remaining 14,000 blocks contain stored data. Data samples and recorder events, such as resets, are logged in the stored data section.

The Host Interface Program writes the data collection parameters (sampling rates and time reference) in the data file on the CEM Disk. When the disk is inserted into the data recorder, the recorder's computer reads the configuration information on the disk, sets the time reference, and begins data collection according to the stored parameters. The data recorder begins adding data to the collected data region of the disk at the end of the existing data record. If the disk has been erased by the host system, the recorder begins to add data samples at the beginning of the data storage space.

Several types of data elements are stored in the data storage space. They include processor resets and data samples. During debrief, when the session is saved, the Host Interface Program reads the data section of the session file and parses the information according to data type. Once parsed, the special elements are used to update the sensor status information displayed on the main control panel of the CEM Host Interface Program. The remaining data samples are written to text data files on the host computer.

These data are read and parsed into six data files by the Host Interface Program. The resulting data files can be read and displayed using common tools such as Microsoft Excel.

3.1 Processing and Saving Collected Data

To process and save collected data, the user browses to the CEM Input File "CEM.txt" on the CEM Disk, identifies a target directory on the host computer for the processed files, and selects "Save Session" on the main control panel. Selection of the CEM Input File and target directory for the processed files is accomplished by selecting the "Browse" buttons on the main control panel. Figure 3.2 shows the open dialog box that appears after selecting "Browse" next to the "CEM Input File" text box. This dialog is used to identify the file "CEM.txt" on the CEM Disk.

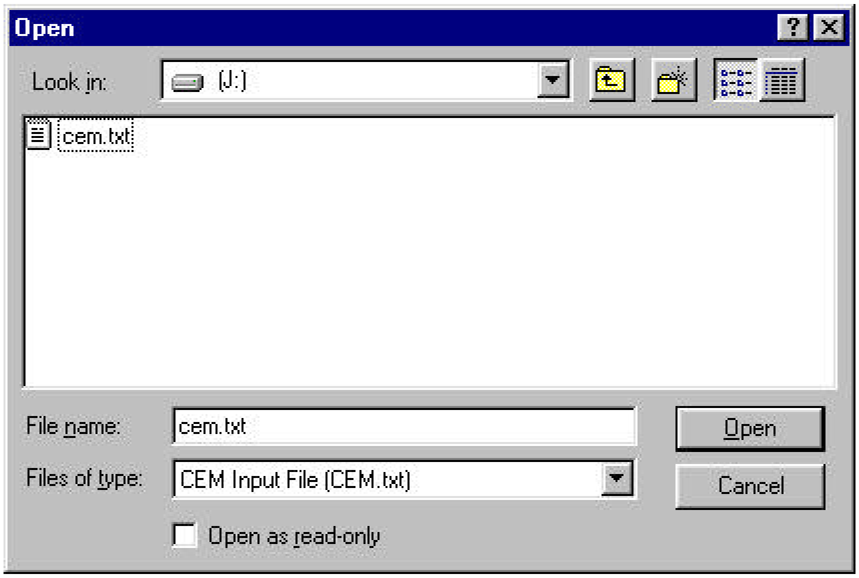


Figure 3.2: File dialog box used to browse to CEM Input File "CEM.txt".

Figure 3.3 shows the save dialog used to select the target directory for the processed data files. The actual names of the six data files created during the save session command processing are computer generated, and the browse process only identifies the target DIRECTORY. If the computer-generated files exist in the selected directory, an error occurs and the user must select a different directory.

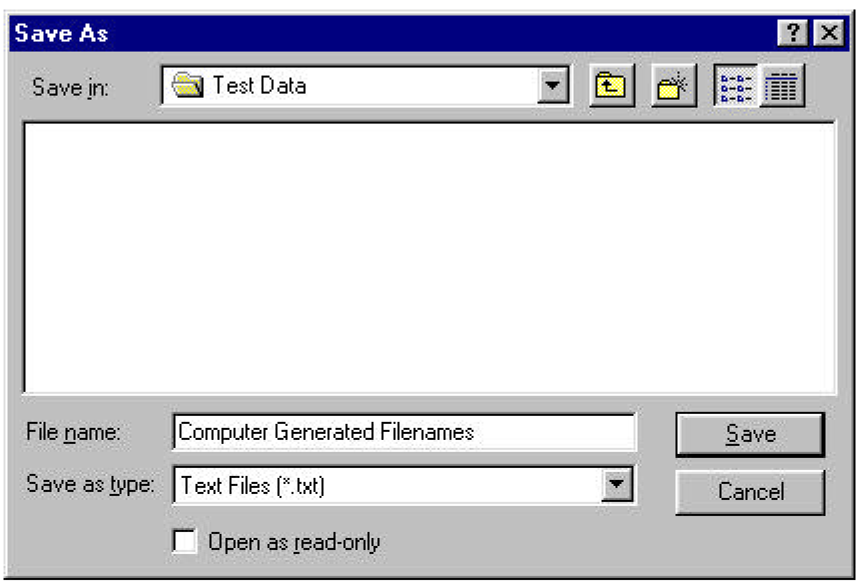


Figure 3.3: File dialog box used to select target directory for processed data files.

After the CEM Input File and target directory for the processed files have been selected, the user may select and execute the "Save Session" command. The filename and target directories are shown in the text boxes on the main control panel. After selecting the "Save Session" command, a progress dialog box appears and tracks the processing and save functions. The box shows the current and total number of data blocks in the CEM Input File. The process can consume several minutes, depending on the speed of the host computer and the amount of data in the data file. Figure 3.4 shows the progress dialog.

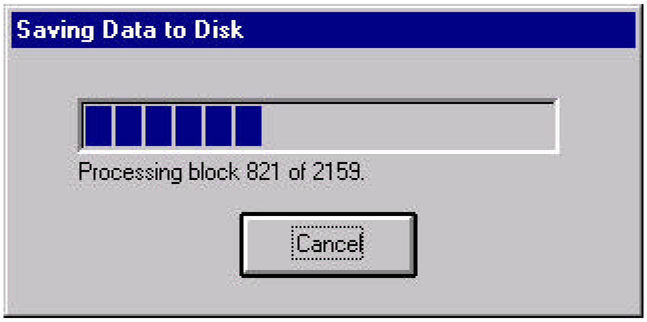


Figure 3.4: Progress dialog displayed during CEM session command execution.

System Status Information

When the save session command is complete, the System Status and Battery Condition sections of the main control panel are enabled and data obtained from the processed file are displayed. In the System Status frame, the Recorder Serial Number of the device that stored the samples on the CEM Disk is displayed. If the data have been stored from more than one recorder (a practice highly discouraged), the string "multiple" will show in the serial number text box. The total number of data samples contained in the data file is displayed, as is the total number of recorder resets encountered during data collection. Recorder resets are logged in the data files when the CEM Disk is inserted into the data recorder.

Battery Life Indicator

Samples of the battery voltage are automatically stored in the recorded data file at the rate of the most frequently sampled data type. By matching the battery voltage samples to the most frequent user-selected sampling rate, it is ensured that reading the battery voltage will not cause unnecessary energy consumption during recording. After saving the session, the Battery Condition section of the main control panel is activated. This section shows the last recorded battery voltage and the percent life remaining as a first-order linear representation of the voltage span beginning at 4.5 V (0%) and 6.40 V (100%). These ranges span the useful life of four alkaline batteries. The first-order approximation is a rough indication of percent life remaining; for a more accurate number, the user must evaluate the current voltage level against the life curve for the specific cells employed during data collection. The data recorder continues to operate at voltage levels below 4.5 V, and will continue down to around 4 V, but the internal sensor referencing circuit begins to tail off at 4.5 V, causing the calibrations to go out of specification. Data collected with the battery voltage less than 5.0 V should be considered inaccurate.

Figure 3.5 shows the main control panel after the "Save Session" command has been executed.

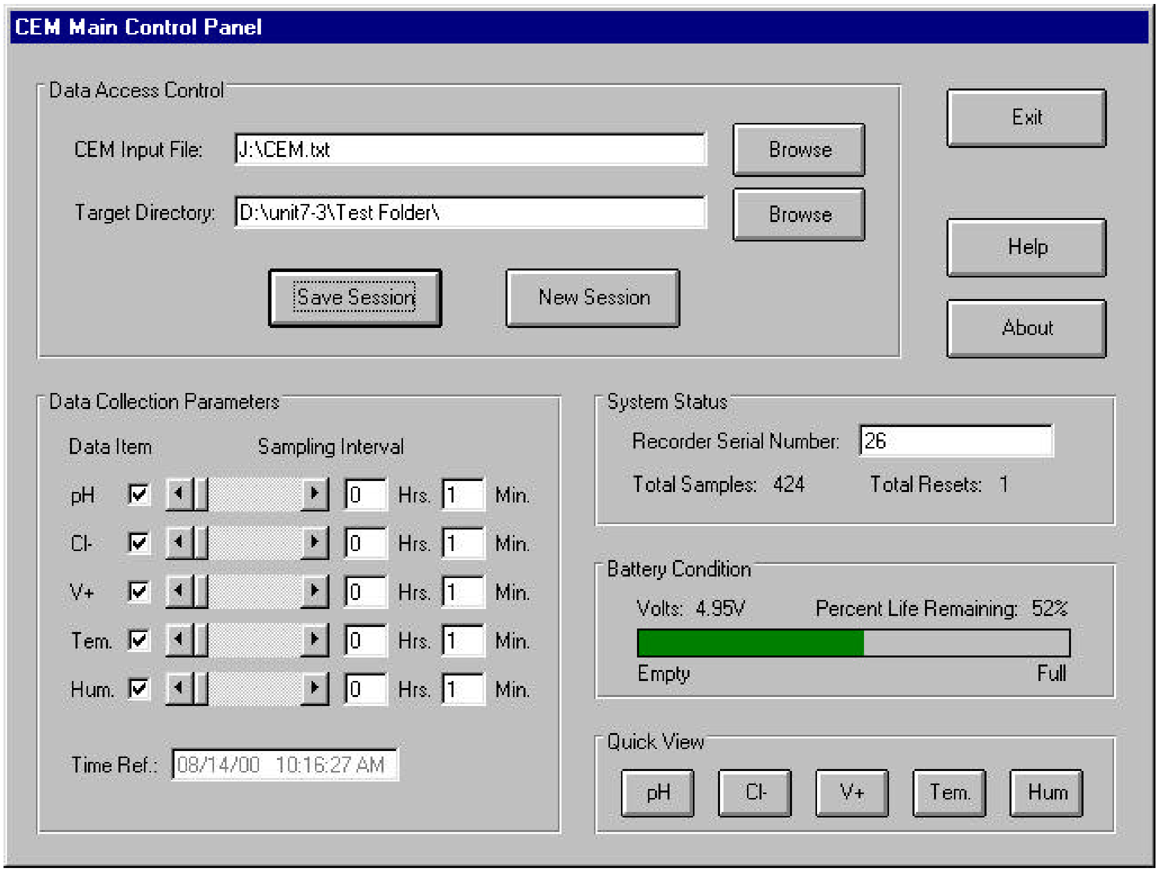


Figure 3.5: CEM main control panel after processing and saving data.

Recorded Data Files

During the execution of the "Save Session" command, the host interface program creates six data files in the selected target directory. The data file names are computer generated and are of the format "<filename(<date.created>).txt." The <filename> parameter is one of six values: Battery, Cl, Humidity, Ph, Temperature, or Voltage. The <date.created> parameter is obtained from the system date on the host computer. Figure 3.6 shows the contents of the target directory after the "Save Session" command has been executed.

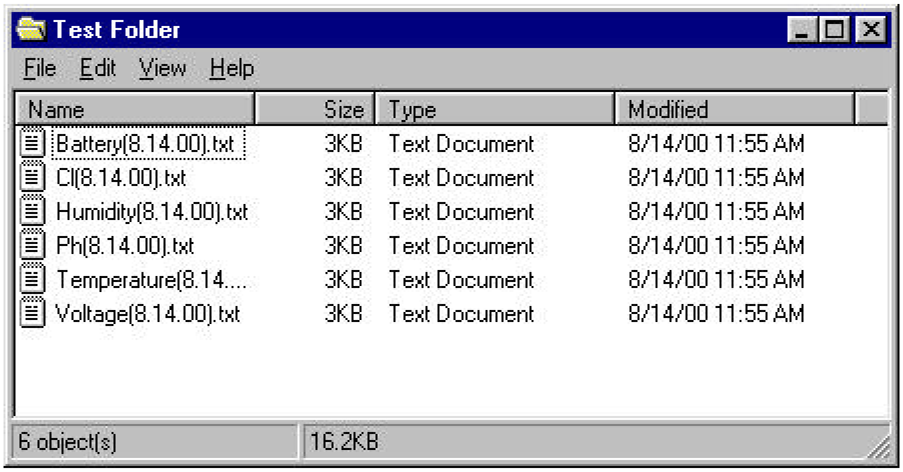
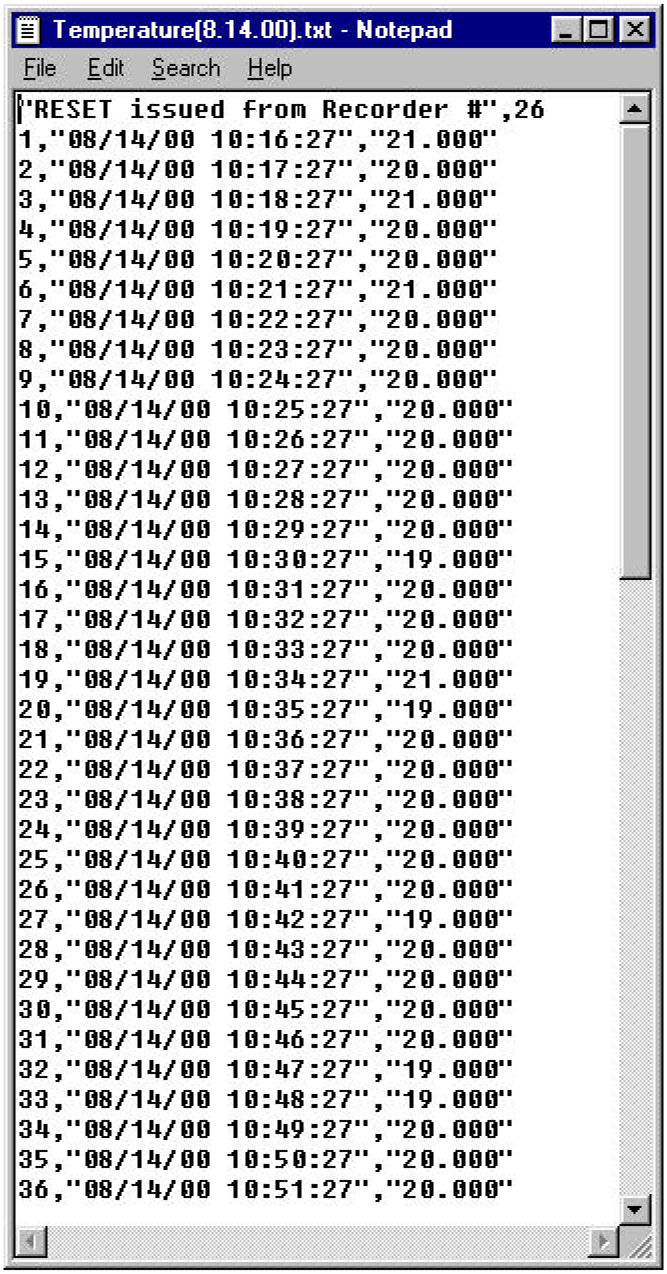


Figure 3.6: Contents of the target directory after the "Save Session" command has been executed.

File Formats

The recorded data files are text-readable documents. Selecting the "Quick View" buttons for each data type opens the corresponding file in the target directory with the wordpad text viewer. Each file contains three columns of data separated by commas. The first column contains a sample number index, the second the recording time of the sample relative to the time reference, and the third, the calibrated value of the sample. The units of all samples are volts except for temperature, which is in degrees Celsius, and humidity, which is in percent relative humidity. The calibration constants used to determine the values of temperature and humidity are coded directly in the host interface software and represent nominal values as given by the sensor manufacturers. Process variances have not been included in the calibrations.

The sample times listed in the recorded data files are reconstructed using the specified time reference as a starting point and the stored sampling intervals as additions between samples. An independent real-time clock is contained in the data recorder. A more detailed discussion of this and related topics can be found in Section 3.2, Data Collection Parameters. Section 4 details the use of Microsoft Excel for plotting and trending the recorded data types. Figure 3.7 shows a stored data file as viewed using the "Quick View" functions.



Temperature(8.14.00).txt - Notepad

File Edit Search Help

```
"RESET issued from Recorder #",26
1,"08/14/00 10:16:27","21.000"
2,"08/14/00 10:17:27","20.000"
3,"08/14/00 10:18:27","21.000"
4,"08/14/00 10:19:27","20.000"
5,"08/14/00 10:20:27","20.000"
6,"08/14/00 10:21:27","21.000"
7,"08/14/00 10:22:27","20.000"
8,"08/14/00 10:23:27","20.000"
9,"08/14/00 10:24:27","20.000"
10,"08/14/00 10:25:27","20.000"
11,"08/14/00 10:26:27","20.000"
12,"08/14/00 10:27:27","20.000"
13,"08/14/00 10:28:27","20.000"
14,"08/14/00 10:29:27","20.000"
15,"08/14/00 10:30:27","19.000"
16,"08/14/00 10:31:27","20.000"
17,"08/14/00 10:32:27","20.000"
18,"08/14/00 10:33:27","20.000"
19,"08/14/00 10:34:27","21.000"
20,"08/14/00 10:35:27","19.000"
21,"08/14/00 10:36:27","20.000"
22,"08/14/00 10:37:27","20.000"
23,"08/14/00 10:38:27","20.000"
24,"08/14/00 10:39:27","20.000"
25,"08/14/00 10:40:27","20.000"
26,"08/14/00 10:41:27","20.000"
27,"08/14/00 10:42:27","19.000"
28,"08/14/00 10:43:27","20.000"
29,"08/14/00 10:44:27","20.000"
30,"08/14/00 10:45:27","20.000"
31,"08/14/00 10:46:27","20.000"
32,"08/14/00 10:47:27","19.000"
33,"08/14/00 10:48:27","19.000"
34,"08/14/00 10:49:27","20.000"
35,"08/14/00 10:50:27","20.000"
36,"08/14/00 10:51:27","20.000"
```

Figure 3.7: Quick View of the temperature data file.

3.2 Data Collection Parameters

The parameters that define data collection are written by the Host Interface Program to a special section on the PC Card during execution of the "New Session" command. The "New Session" command can only be executed after the CEM Input File has been identified and the data collection parameters have been set. The data collection parameters are set either by adjusting the values as they appear on the main control panel or saving the session contained on the CEM Disk. Saving the session loads the existing data collection parameters.

Execution of the “New Session” command causes the data collection parameters displayed on the main control panel to be written to the configuration section of the CEM Disk. The data section of the CEM Disk is erased. Figure 3.8 shows the main control panel with an input file selected and data collection parameters specified.

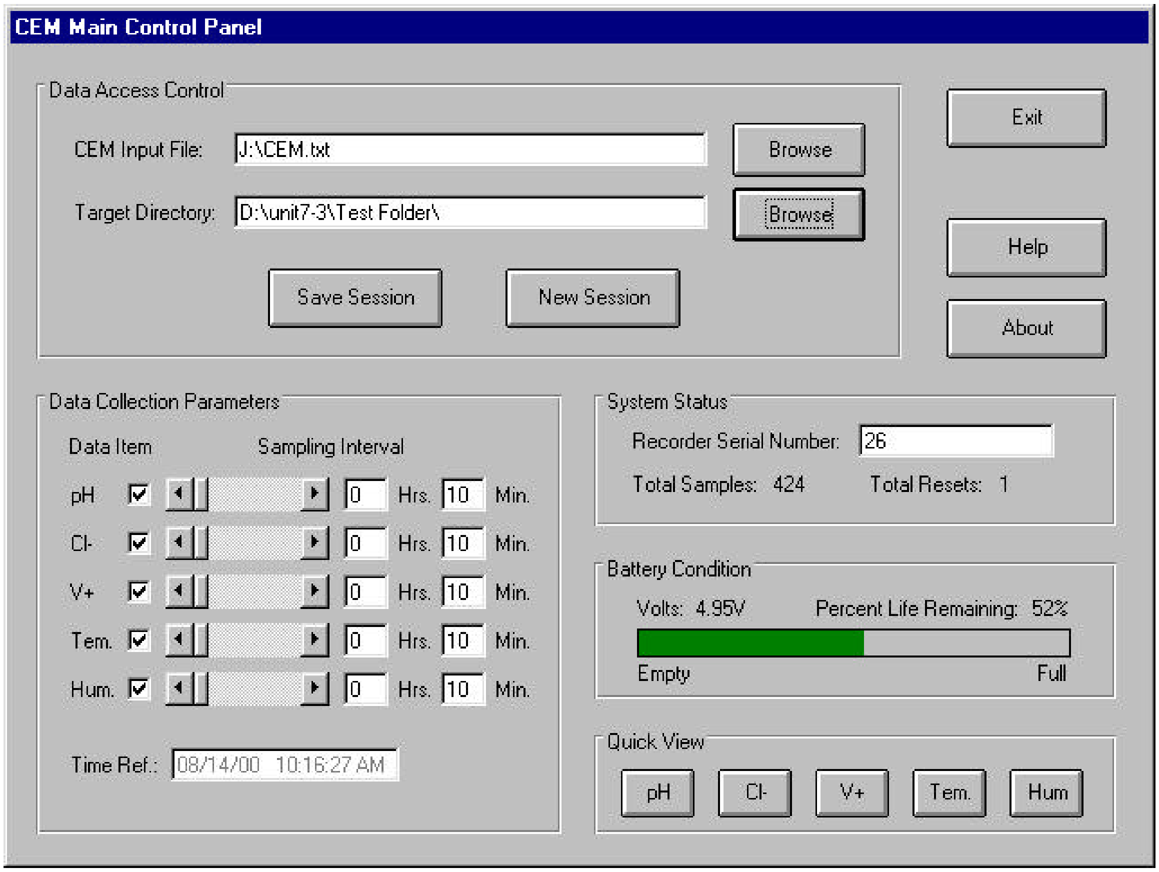


Figure 3.8: Main control panel with input file and data collection parameters specified.

When the CEM Disk is removed from the host computer and inserted in a data recorder, the configuration section is read, and data collection begins according to the stored data collection parameters.

The data collection parameters consist of an enable item and sampling interval for each of the five types and a time reference used to reconstruct sample times during debriefing (session saving). Each of the five data types is enabled by selecting the corresponding check box in the Data Collection Parameters frame on the main control panel. The corresponding sampling interval for each sample type is set by adjusting the slider next to the check boxes. The sampling interval can range in frequency from one sample per minute to one sample every 255 hours and 59 minutes. Adjust the interval by minutes by selecting the slider arrows and by hours by clicking above and below the slider on the bar face.

The setting of sampling intervals directly affects power consumption and battery life in the data recorder. The more frequently samples are taken, the more power is consumed. Section 5 presents a detailed discussion on power consumption.

A sixth data type, battery voltage, is automatically enabled and set to a sampling interval equal to the most frequent user-selected value. This ensures that the battery voltage samples will only occur concurrently with other samples, thereby conserving power by never actually causing a power-up.

The time reference is stored on the CEM Disk in the configuration data space. The time reference is set when an erased CEM Disk is placed in the data recorder. The real-time clock contained within the data recorder sets the time reference on the data recorder configuration cycle. The time reference is used during collected data processing, along with the sampling interval information, to derive real-time stamps for each element of collected data. The time reference is used as the start time, and the sample times are computed by adding sampling intervals. For example, presume the data recorder is configured to store temperature samples at 1-hour intervals and the time reference is January 1, 1998, 12:00 PM. If, when saving the session, 10 samples of temperature exist in the data file, they are assigned sample times of 1:00 PM, 2:00 PM, 3:00 PM, etc.

System Resets

When the CEM Disk is inserted in the recorder, the recorder reads the configuration information contained on the card and begins collecting data according to the parameters. After reading the configuration information, the recorder writes a *reset* element to the data recording space on the disk. If the disk has been erased by the host control program, the *reset* event is at the beginning of this data file. The *reset* event contains the serial number of the recorder that issued the reset. Every time the card is inserted into the recorder, a *reset* event is generated and recorded.

During the processing of the recorded data file by the host system, the number of *reset* events contained in the data file is counted and displayed in the status frame. The serial number associated with the *reset* event is displayed in the serial number window. A unique serial number is associated with each recorder. The flash disks are generic, as is the host interface software.

If a flash disk is moved from one recorder to another without erasing the data file, multiple serial numbers will be recorded in the file. This is not an error, but it does make the logistics of tracking the different regions of the data set more complicated. If more than one serial number exists in the data file, the message “multiple” will appear in the serial number text box. It is recommended that the CEM Disks only be used with a single recorder between erase procedures.

The architecture of the data recorder has several levels of data caching. This is done to limit the number of block writes to the CEM Disk during data collection and conserve power. Depending on the system data collection parameters, these cache spaces are transferred to the nonvolatile portions of the flash disk at different intervals. Some data and events may not be written to the CEM Disk if the system does not operate over a certain defined interval. A total of 86 samples are stored in the cache before each block write to the CEM Disk. Therefore, if all five data items are enabled and selected to sample every minute (plus one sample per minute for the battery voltage), a total of about 15 minutes of recording must occur before any samples will be written to the disk. Similarly, depending on when the card is removed from the data recorder, up to 86 samples will be lost.

Erasing the Data File

The data file “CEM.txt” contained on the CEM Disk should only be manipulated using the CEM Host Interface Program. Due to the system constraints of the data recorder, a much abridged set of file management functions has been implemented to manipulate the data file on the CEM Disk. In fact, the logical *location* and *size* of the file is assumed fixed by the recorder. The file has been created by the manufacturer and must not change in location or size on the CEM Disk for the data recorder to operate. Both the recorder and the Host Interface Program *modify* the file without changing its logical location or length. Regular Windows95 and DOS-supported file manipulations obviously allow differing length and fragmented files. The fragment information and file structure is written to configuration sections of the disk that allow the operating system to reconstruct the files during access. The CEM data recorder supports none of this functionality. If a file manager directly manipulates the disk, the file may become fragmented or relocated. The file would still appear normal to the Windows95 (or other) operating system but would not function in the CEM recorder system. There is no need to modify the file directly. Unfortunately, there is no simple way of blocking direct file system access to the disk while allowing the host program access. So it is left to the user to ensure that the data file is not manipulated.

If the file "CEM.txt" is accidentally corrupted on one of the CEM Disks, use the following procedure to recover:

- Format the CEM Disk under Windows95;
- Copy the file "CEM.txt" from the BACKUP DATAFILE directory on the media CD-ROM.

If this fails to correct the problem, send the disk back to Honeywell for reformatting.

To erase the data on a CEM Disk and start a new recording session, begin by specifying the CEM Input File on the main control panel. The erase procedure itself is a time-consuming operation. During normal Windows95-supported file erasure, the configuration section of the disk is simply reset to not point to the file data. Subsequent disk operations will use the space formerly occupied by the erased file as needed. The CEM system writes blank information to the CEM data file over any collected data that is in the file. The procedure is more like a format command, in that individual elements are reset to a known (blank) state. A progress bar is displayed to show the user how the erase procedure is progressing. Figure 3.9 shows the progress form. On a 100-MHz PC, the procedure takes approximately 10 minutes.

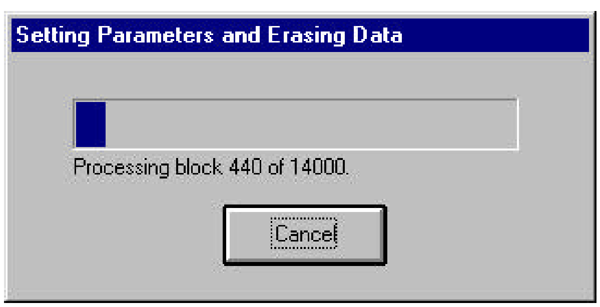


Figure 3.9: Progress form for erase procedure.

3.3 System Information

Version information for the CEM Host Interface Program and other system information can be obtained by selecting the "About" button on the main control panel. Figure 3.10 shows the about panel.

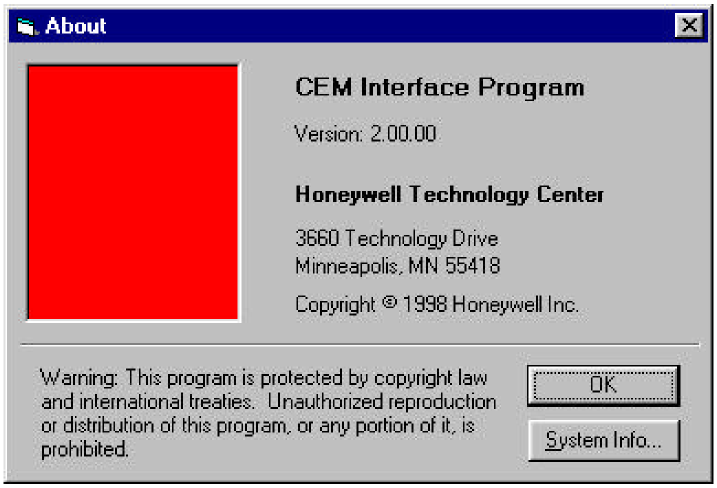


Figure 3.10: Host Interface Program About panel.

Section 4
Analyzing Processed Data Files

Depending on the data collection parameters, up to five recorded data files plus the battery voltage data file are created by the Host Interface Program during “Save Session” command execution. These files are formatted in three columns of text-readable characters interspersed with two column rows of system reset tokens. The three columns of each row of data samples are index (sample number), timestamp, and value. The two columns of each row of reset tokens are reset identifier and recorder serial number. The data files can be imported into most existing data analysis tools such as Microsoft Excel as formatted ASCII files. The procedure for inputting and plotting data in Microsoft Excel is outlined in this section. In this example, Microsoft Excel 98 (version 8.0) was used running in WindowsNT 4.0.

Launch Excel. From the File menu, choose Open. In the Open dialog box, select file type “All Files.” Browse to the target directory that contains the data files and select one of the text files. Figure 4.1 shows the Open dialog box configured to open a Humidity data file.

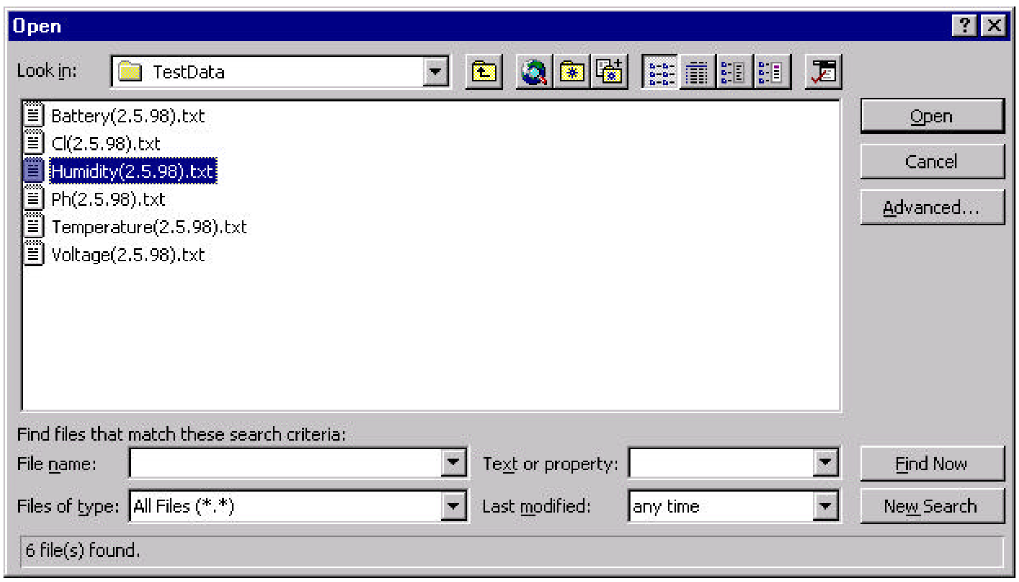


Figure 4.1: Microsoft Excel importing a recorded data file.

When Excel attempts to load the file, it recognizes the contents as readable ASCII and launches the text import wizard. There are three steps in the import wizard. Figure 4.2 shows step 1, where the user identifies the input file as a delimited ASCII file.

Figure 4.3 shows step 2 of the import wizard, where the user identifies comma delimiters and verifies that the column breaks are aligned with the text columns. The final step of the import process is specifying the data format of the numbers contained in the columns.

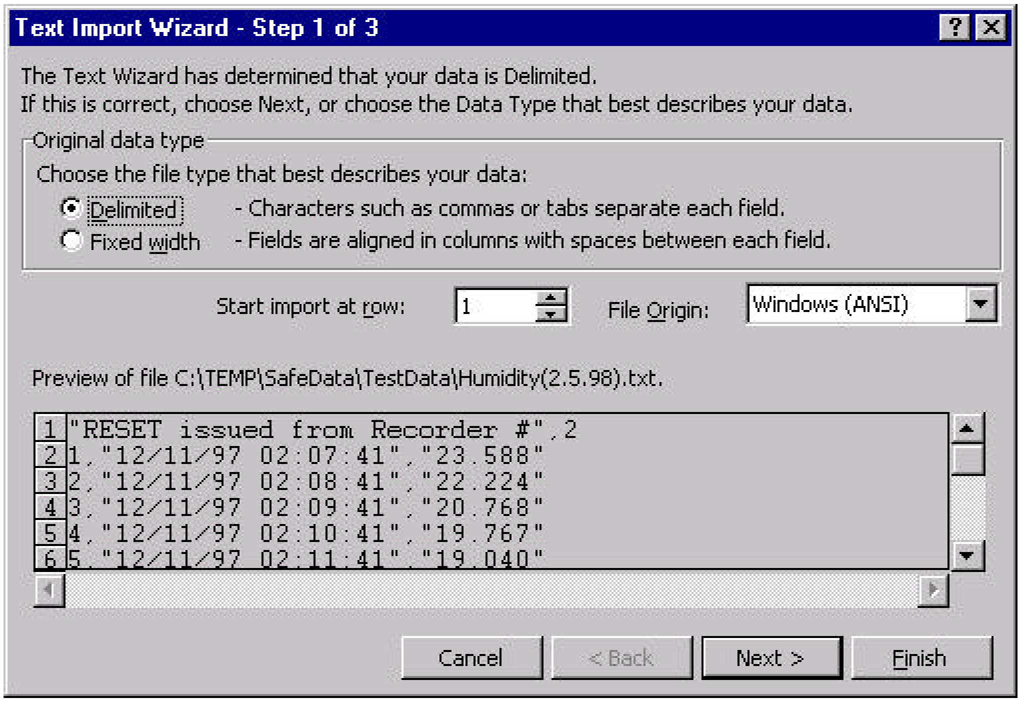


Figure 4.2: Step 1 of the Excel text import wizard.

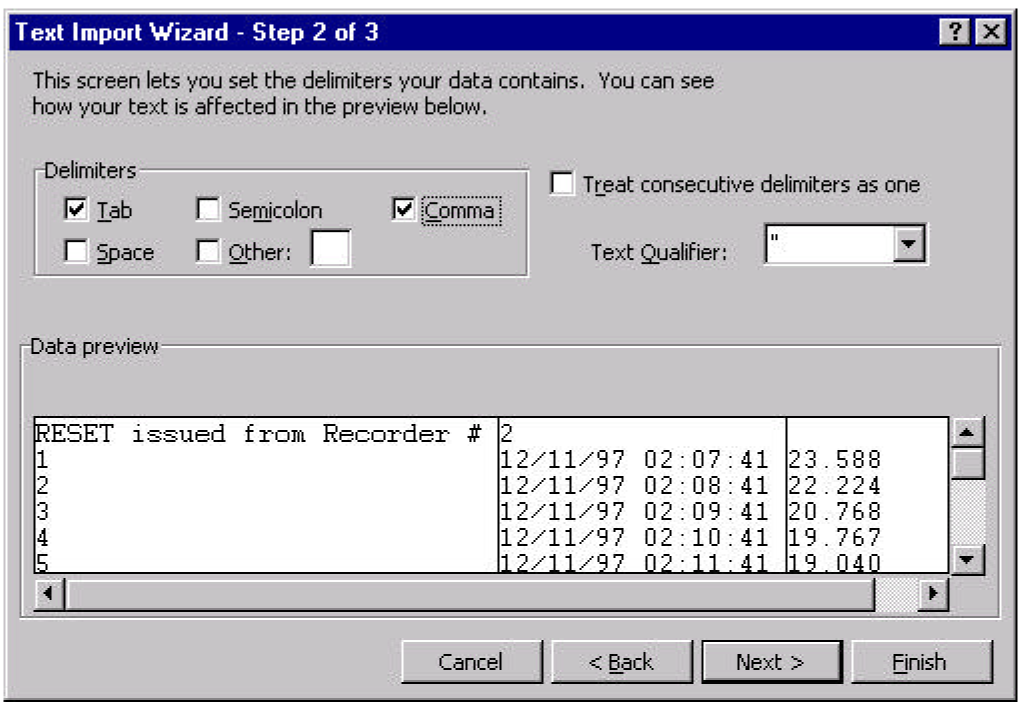


Figure 4.3: Step 2 of the Excel text import wizard.

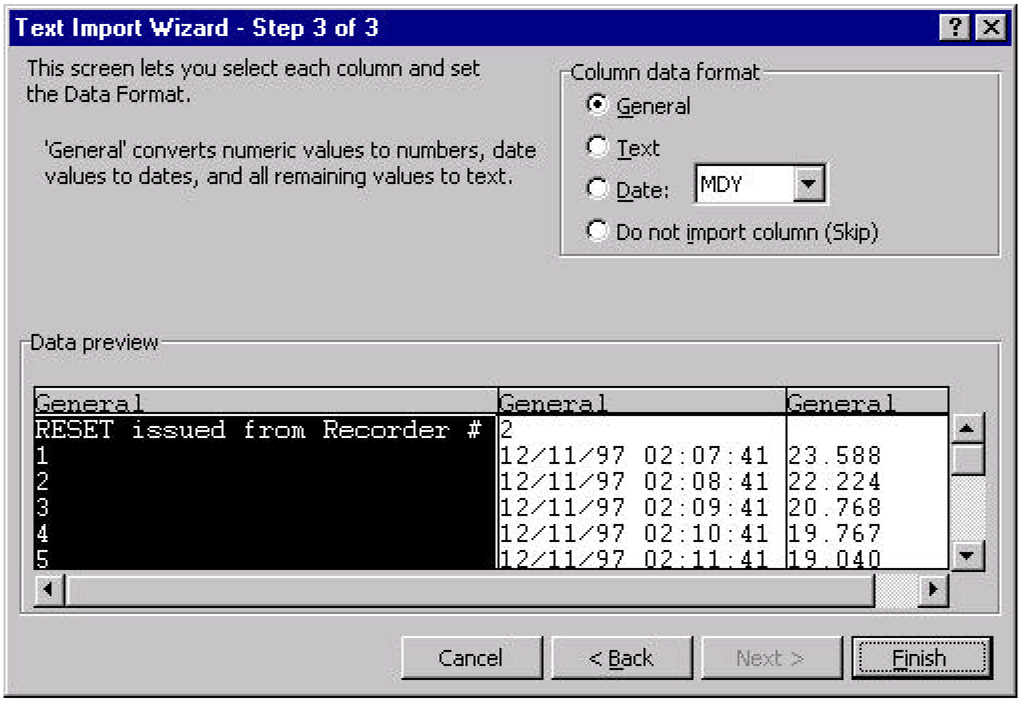


Figure 4.4: Step 3 (final step) of the Excel Text Import Wizard.

After importing the data file and adjusting the column widths to fit the number of characters, the data elements appear in the columns of the spreadsheet. Figure 4.5 shows the data in the spreadsheet. The reset token, issued from recorder #2, can be seen on the first line.

A plot of the data versus the sample number can be obtained by selecting two columns of the data and launching the chart wizard. To select multiple nonadjacent columns in Excel, push the column header designator of the first column, hold the ctrl key, and push the column identifier of the second column. To launch the chart wizard, select the chart wizard button (multicolored bar graphs) on the icon menu. Figure 4.6 shows the index and value columns selected just prior to launching the chart wizard.

After launching the chart wizard, select the “scatter plot with data points connected by lines” option and then choose “Finish.” This selection is shown in Figure 4.7.

The resulting plot is shown below in Figure 4.8. The plot can be modified to include axis labels, a title, etc. A similar procedure can be followed using the sample times to obtain a plot of time versus relative humidity.

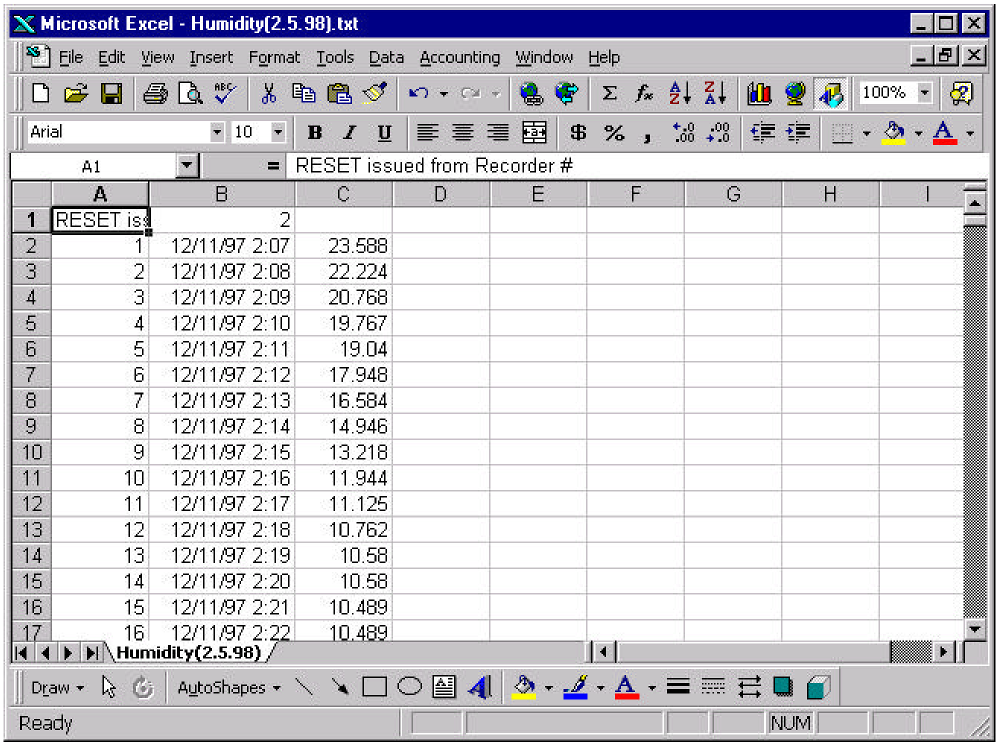


Figure 4.5: After importing, the data fit into the columns of the spreadsheet.

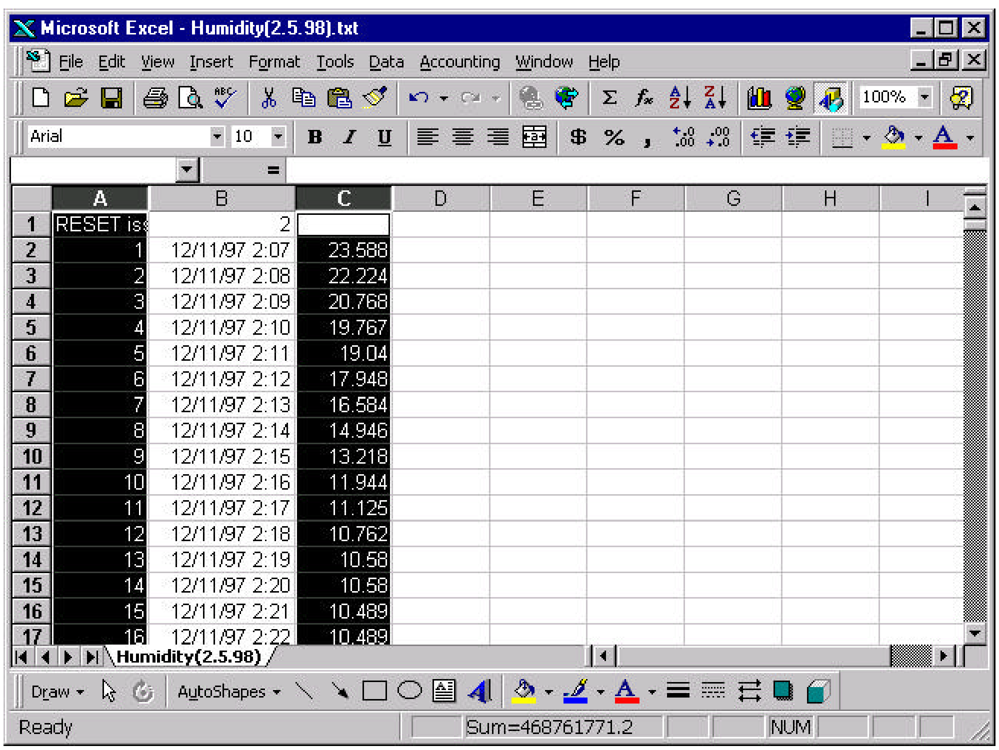


Figure 4.6: Selected index and value columns in Microsoft Excel.

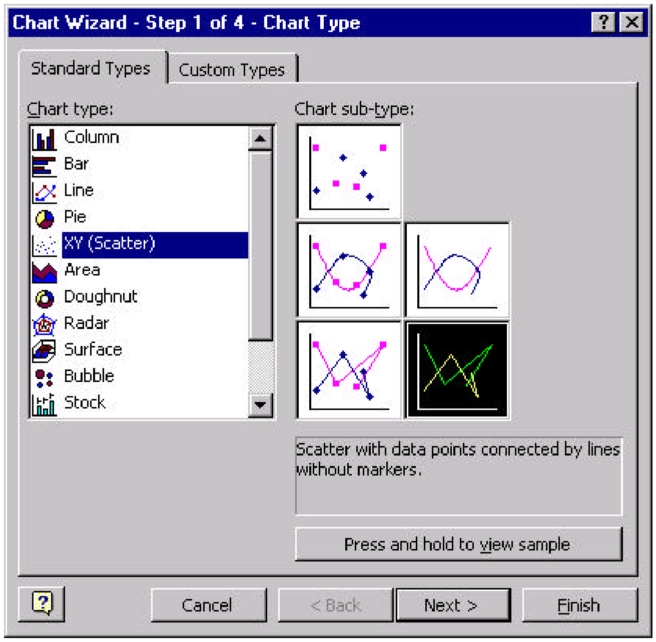


Figure 4.7: Select scatter plot with data points connected by lines.

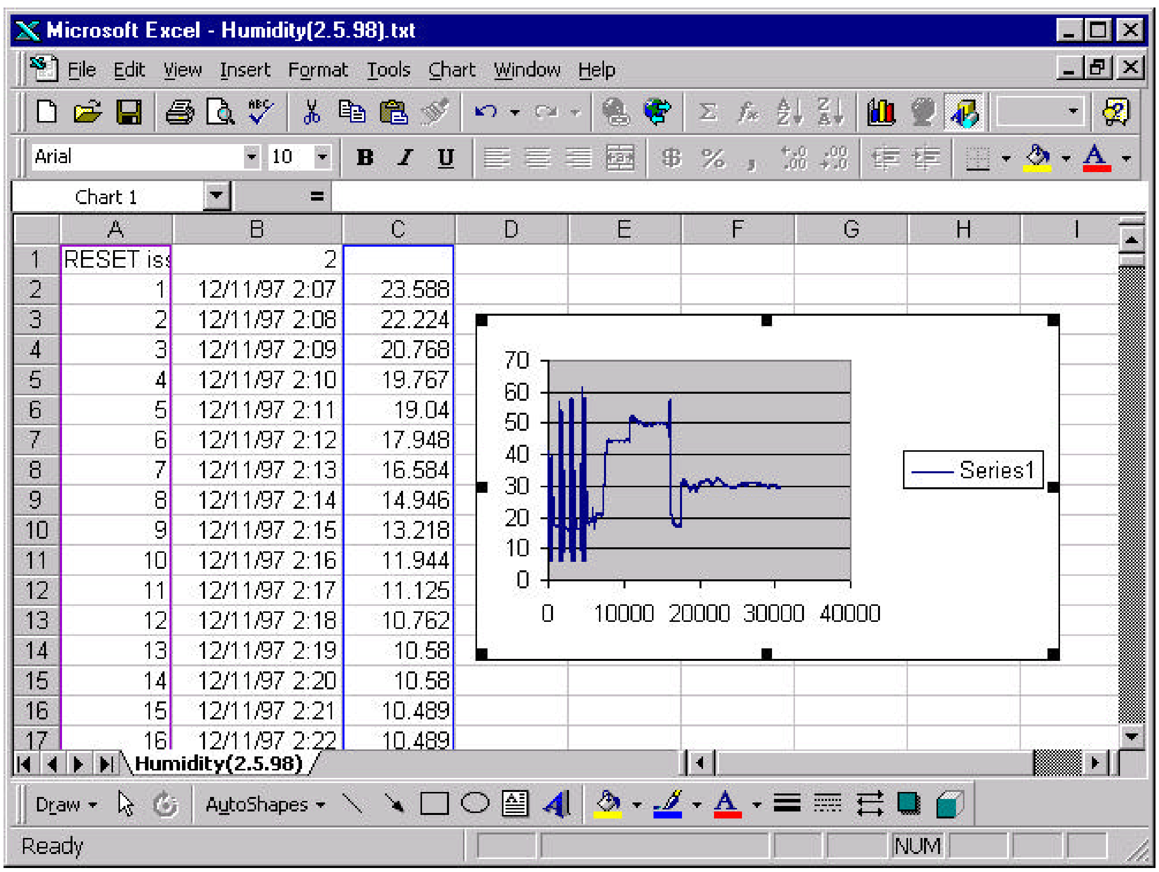


Figure 4.8: Completed plot.

Section 5
Recorder Batteries

The recorder uses four AA alkaline batteries. The life of the batteries is correlated with the sampling rate of the recorder.

5.1 Calculating Operating Life

This section will go over the numerical analysis of the battery voltage level as a function of both time and sampling rate. The use of the LCD display will also shorten battery life. The following analysis excludes the use of the LCD display, since the assumption is that the display will be used infrequently. Data were collected over six trial runs, each lasting between two weeks and six months. Sampling rates for each trial remained fixed and ranged from one sample per hour (S/Hour) to 60 S/Hour. Battery voltage levels were sampled each cycle, along with other project-specific environmental attributes. The batteries used during these tests were Rayovac “heavy duty” AA alkaline cells.

There are three distinct stages of behavior for the project battery. The first stage is an exponential decay from the starting voltage level to approximately 5.9 V. The second stage is a linear decay from 5.9 V to approximately 5.2 V. Beyond this point, data are only available for one of the six trials. In this case, a third stage appears as a relatively flat voltage level over time until a certain point, at which terminal decay begins. The battery voltage of 5.2 V will be considered the point at which the battery life has ended.

Breaking the life of the battery into two stages, it is possible to obtain functional relationships between voltage level, lifetime, and sampling rate. Table 5.1 shows some key values used in the derivation of these relationships.

Table 5.1: Summary of Key Values.

#	Rate	V_{start}	$T_{Start - 5.9V}$	Linear Slope
1	60/hr	6.45V	7,800min	-20.45 μV/Cyc
2	60/hr	6.30V	5,760min	-20.04 μV/Cyc
3	60/hr	6.40V	5,520min	-20.12 μV/Cyc
4	4/hr	6.40V	69,120min	-23.04 μV/Cyc

5	2/hr	6.40V	103,680min	-25.12 µV/Cyc
6	1/hr	6.40V	139,680min	-32.24 µV/Cyc

Although it would be difficult to characterize the exponential decay rate of stage 1, it is possible to define a time and sample rate relationship based on the data obtained. Figure 5.1 shows a curve-fitted relationship between decay time to 5.9 V (normalized to starting voltage level) and sample rate.

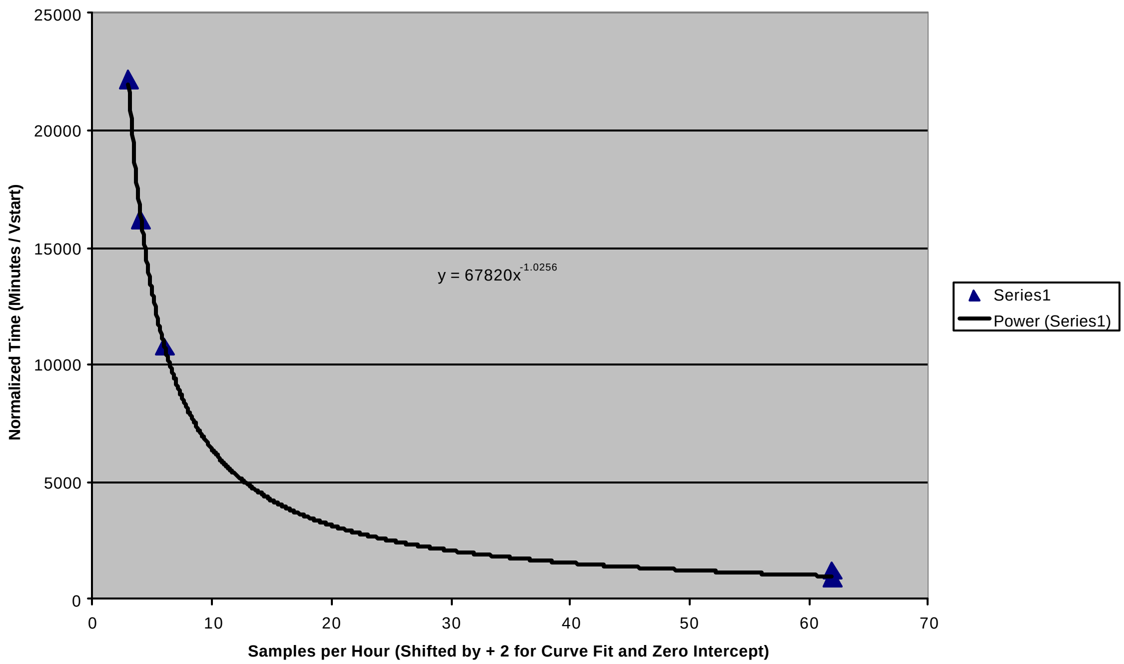


Figure 5.1: Normalized decay time to 5.9 V.

Based on the curve-fitted formula (generated by Microsoft Excel), a sampling rate of zero would yield a decay time to 5.9 V of 33,313*V_{start}. For example, a battery starting at 6.4 V would decay to 5.9 V under no dynamic signal conditions in 213,200 minutes, or 148 days.

Figure 5.2 shows the relationship between sampling rate and linear voltage decay rate found in the stage 2 (5.9 V to 5.2 V) region. This plot was curve fitted for both linear and second order to achieve the best zero intercept approximation given the lack of data between sample rates of 4 and 60.

There is clearly little difference between the curve-fitted formulas for first and second order. Therefore, it is correct to assume that the relationship between sampling rate and linear decay in the 5.9 V to 5.2 V region is linear, with a static decay rate of –11 µV per hour and a dynamic rate of –20 µV per hour per sample/hr. The slope of the decay rate line will provide an easy means of determining the time for a battery to decay from 5.9 V to 5.2 V under any dynamic operating speed.

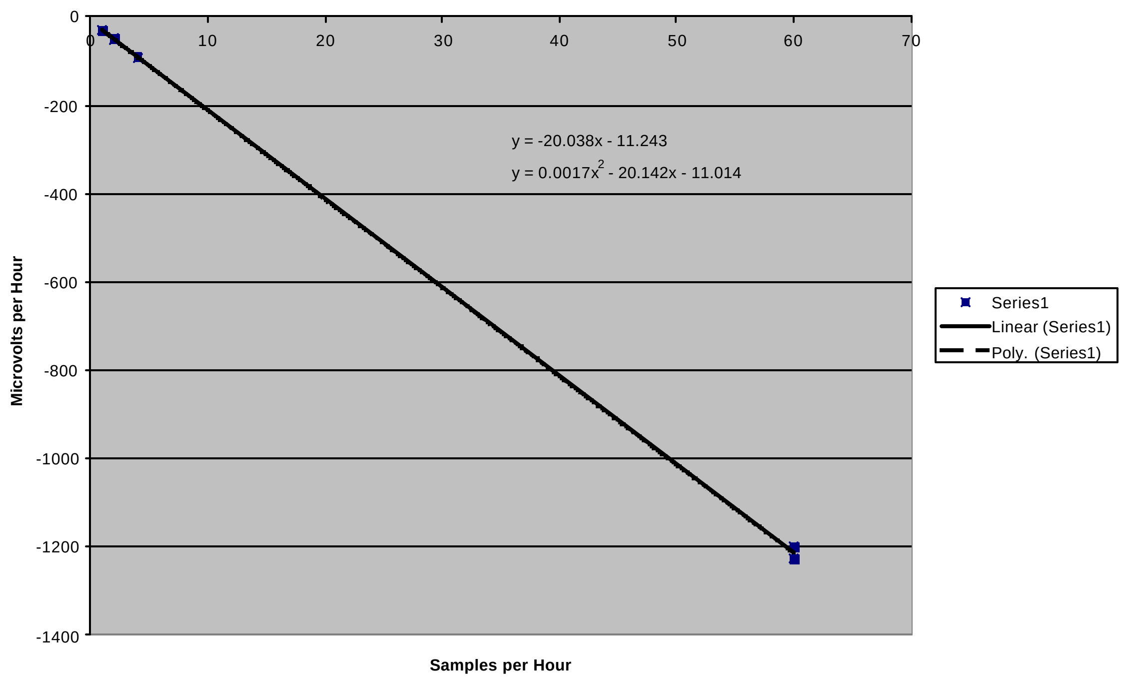


Figure 5.2: Battery voltage decay rates: linear decay region.

A simple formula can now be constructed to characterize the battery lifetime from start to end (5.2 V). The battery will undergo two phases of decay, each with a definable time span, denoted τ_1 and τ_2, where:

$$\tau_1 = \text{Decay time from start to 5.9 V}$$

and

$$\tau_2 = \text{Decay time from 5.9 V to 5.2 V}$$

Borrowing from the curve-fitted formula of Figure 5.2,

$$\mathbf{t_1 = 67{,}820*V_{start}*(x+2)^{-1.0256}\ min}$$

where x is the sampling rate per hour. If a 15% error factor is included, this formula can be readily simplified to:

$$\mathbf{t_1 = 67{,}820*V_{start}*(x+2)^{-1}\ min}$$

The time delay from 5.9 V to 5.2 V can be calculated with sampling rate as the only variable,

$$\tau_2 = (5.2\ V-5.9\ V)*(60min/hour)/(-20.038x - 11.243\ \mu V/hour)$$

$$\mathbf{t_2 = 42*10^6*(20.038x + 11.242)^{-1}\ min}$$

Allowing for a 15% error,

$$\mathbf{t_2 = 4.2*10^6*(2x + 1)^{-1}\ min}$$

Combining the two, a battery lifetime formula is obtained:

$$\mathbf{t_o = t_1 + t_2}$$

$$\mathbf{t_o = 6.78*10^4*V_{start}*(x+2)^{-1} + 4.2*10^6*(2x + 1)^{-1}\ min}$$

where x is the sample rate in samples per hour, and V_{start} represents the new battery voltage level.

The formula for battery lifetime includes static and dynamic power dissipation and, when compared against real data, gives less than 15% error. Table 5.2 gives some extrapolated results based on the battery lifetime formula and a 6.4-V starting voltage. Comparison with actual trial data is given where possible.

Table 5.2: Lifetime equation results.

Rate	τ_1	Test	% err	τ_2	Test	% err	Lifetime
60/hr	6,998	6,370	8.97%	34,711	32,440	6.54%	29 days
30/hr	13,560			68,852			57 days
15/hr	25,525			135,484			112 days
8/hr	43,392			247,059			202 days
4/hr	72,320	69,120	4.63%	466,667			1.02 years
2/hr	108,480	103,680	4.63%	840,000			1.81 years
1/hr	144,640	139,680	3.55%	1,400,000			2.94 years
.5/hr	173,568			2,100,000			4.33 years
.25/hr	192,853			2,800,000			5.69 years
0/hr	216,960			4,200,000			8.40 years

Time values given in minutes unless specified.

5.2 Battery Replacement

The recorder will need its batteries replaced periodically based on the sampling rate and time in use. To replace the batteries in the recorder, first remove the PCMCIA data card from the recorder. Proceed in removing the top cover on the recorder by removing the six screws used to attach the cover. Remove the four AA batteries from the battery holder. To install, carefully place four new AA batteries in the battery holder, observing proper polarity. Reinstall the top cover of the recorder. Insert the PCMCIA data card.

Section 6
Recorder User Interface

This section covers the user interface for the data recorder. The data recorder supports seven modes of operation. A user can obtain the current readings of each sensor electrode in the system. Details will be discussed in the following sections.

6.1 LCD Display and Buttons

The user interface to the Data Recorder consists of a LCD display and 4 push buttons. The front cover of the Data Recorder is shown in Figure 6.1.

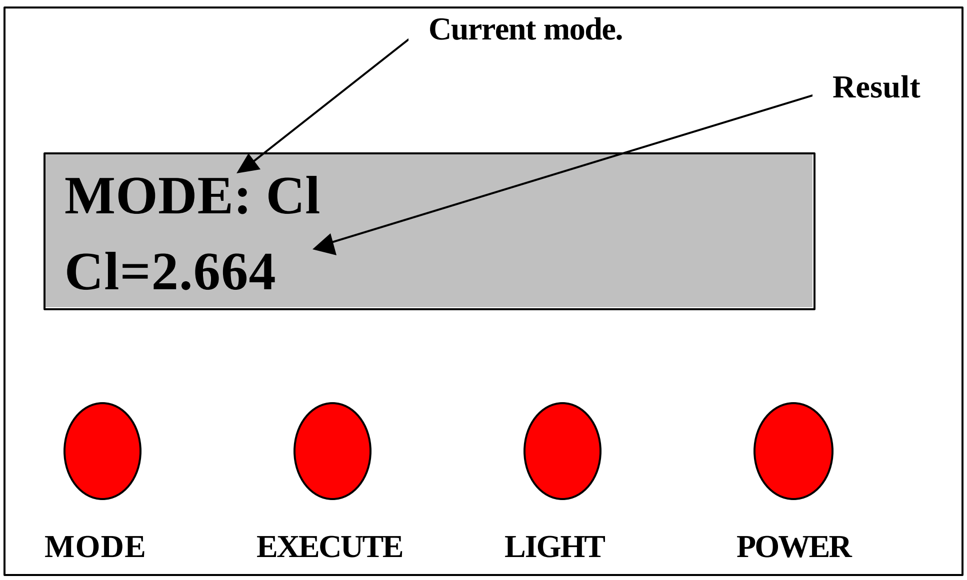


Figure 6.1: Front cover of data recorder.

The display contains two lines:

1. Current Mode—Tells the currently selected mode.
2. Result—Shows the results of the current mode after execution of a mode.

The four push buttons are described as follows:

1. Mode—Used to select among the seven available modes.
2. Execute—Used to execute the selected mode.
3. Light—Turns on/off the backlight on the LCD.
4. Power – Turns on/off the LCD power.

6.2 Modes of Operation

The data recorder user interface has seven modes of operation as described below:

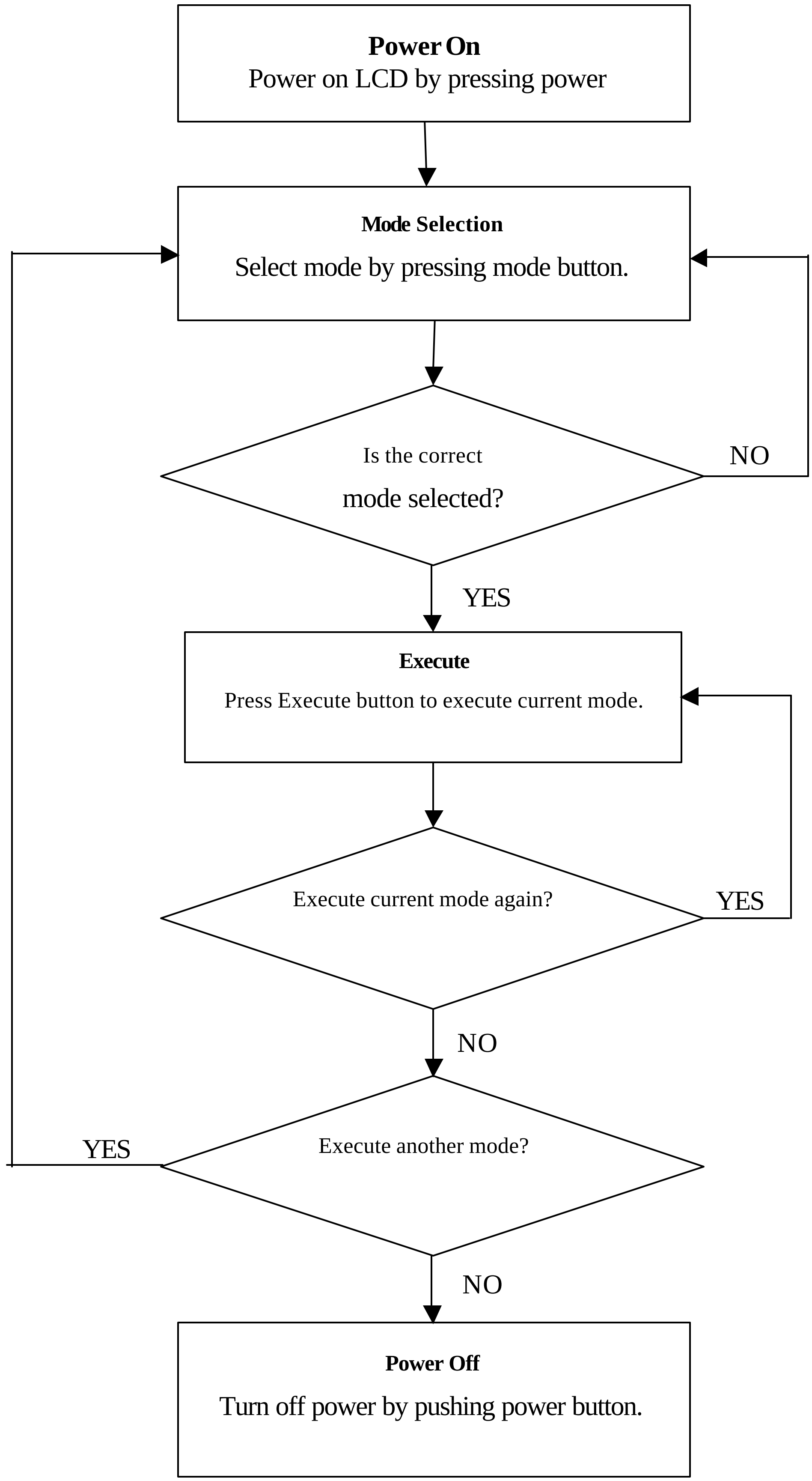
1. **Self Test**—This mode is used to test the system. When it is executed, the output will indicate the status of the system. “System Okay” is the normal response when executed. If there is a problem with one of the sensors in the system, the response will indicate the sensor that failed.

An example response for a Ph sensor failure is as follows: “Failure=>Ph.” When a system is first powered up, running a self-test is recommended to check the system.

2. **CL**—Mode used to measure the chloride ion electrode. The output of this mode is the measured potentail in volts from the sensor output.
3. **Ph**—Mode used to measure the Ph electrode. The output of this mode is the measure potential of the Ph sensor in volts from the sensor.
4. **Temp**—Mode for measuring the temperature electrode. The output is the measured potential from the temperature sensor in volts. Refer to Section 6.4 for the potential to degrees Celsius conversion table.
5. **Free Pot**—Mode for measuring the free-potential electrode. The ouput is the measured potential from the free-potential electrode in volts.
6. **Humid.**—Mode for measuring the humidity electrode. The output is the measured potential from the humidity sensor in volts. See Section 6.4 for the potential to percent relative humidity conversion table.
7. **Battery**—Tests the batteries in the system. Normal response is “Battery Okay.” If the batteries are low, the output will state “Battery Low,” and the batteries should be replaced.

6.3 Operation of the Interface

The following flow chart indicates the sequence of events needed to take a sample with the interface.


Power On
Power on LCD by pressing power
Mode Selection
Select mode by pressing mode button.
Is the correct
mode selected?
NO
YES
Execute
Press Execute button to execute current mode.
Execute current mode again?
YES
NO
Execute another mode?
YES
NO
Power Off
Turn off power by pushing power button.